Proposed Scheduling Methods for Printed Circuit Board Assembly

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ABSTRACT

The current practice in the assembly of electronic components on printed circuit boards (PCB's) is serial production, a process characterized by very long set-up times.

However, with the advent of efficient on-line process information, new production control methods are now possible. This paper proposes two new production methods - the Grouped Set-up (GSU) method and the Sequence- Dependent Scheduling (SDS) method, which can significantly reduce set-up times.

It is shown that the GSU always performs better than the SDS method in terms of total production flow (throughput), while the SDS performs better than the GSU method in terms of work-in-process (WIP) inventory.

KEY WORDS

Scheduling, Printed Circuit Boards, Grouped Set-Up, Sequence-Dependent, Flow, Throughput, Work-In-Process Inventory.

INTRODUCTION

The traditional serial production method used in the assembly of electronic components on printed circuit boards (PCB's) requires that new set-ups of all components to be assembled on the machines be done each time the PCB is changed. This procedure results in extended set-up times, since typically, even components that are common to several PCB's, are required to be set-up more than once.

This paper proposes two new production methods - the Grouped Set-up (GSU) method and the Sequence - Dependent Scheduling (SDS) method, which can be used in significantly reducing set-up times. These in turn, may result in increased flow and/or reduced work-in-process (WIP) inventory - both factors that improve the productivity performances of these PCB assembly machines.

The special characteristic of PCB structures is that 20% of all the component types are "highly common", often incorporating about 80% of all components in each PCB. The number of common components appearing in digital PCB's (as compared to analog PCB's) can be even greater than 20% - perhaps upto 60% of all the components used. This characteristic calls for a GT (Group Technology) or, "product based families" concept to be used in the production planning process. The GT approach is defined as: a "classification of the products into groups, calling for the use of similar components, for which production sequences can be developed" (Boyle 1986).

With increasing production demand, it eventually becomes economically justified to dedicate one or more machines for the assembly of the common components (Mangin 1986). This approach is called the "static operating policy" (Lofgren & McGinnis 1986) versus the "dynamic operating policy", in which components are switched to meet the requirements of the subsequent PCB.

A single machine has a production capacity ranging from 50,000 to 75,000 PCB's per shift per year (based on an average of 250 components per PCB (Mangin 1986), and an average machine rate of 6000 component insertions per hour (DynaPert-Precima Ltd. 1986, Universal Instruments Inc. 1986).

In some situations, production volumes may not justify the use of dedicated machines for the assembly of specific components. When smaller numbers of different PCB's are produced, it is often possible to dedicate special locations on the machines for the assembly of common components. However, this usually cannot apply to situations in which many different PCB's are produced - such as found in sub-contractors' plants, where they typically produce to orders from many customers. Such applications involve large numbers of components,of which a good percentage are shared among several PCB's.

Production plans in these environments can be highly flexible; in that it is possible to find many combinations (or, sequences) of PCB's, whose common components vary considerably from one combination to another. Their combined total number of components invariably exceed the machine capacity (machines usually contain from 100 to 300 component locations), so that it is impossible to allocate a fixed location for each common component on the machine.

BASIC ASSUMPTIONS

1. This paper is not concerned with routing the machine's head in assemblying components on a PCB. The routing problem is a separate problem, dealt extensively in the literature.
2. Due-dates are not considered in this paper. The reason is that due-dates considerations usually determine the PCB requirements for the short-term production plan, and the methods described in this paper are designed specifically for short-term production applications.
3. The set-up time considered in this paper applies only to the set-up times needed, when the PCB type to be assembled is changed. Refilling components in the machines during assembly is not considered since the quantity of each component required (which necessitates refilling operations) is independent of the production method used - i.e., whether using the GSU, the SDS or the traditional production method. Also, the refilling operations do not cause the shut-down of the machine, while for set-up change, the shut-down is necessary.
4. The GSU and the SDS methods were developed for the traditional technology used with PCB assembly - i.e., the "thru-hole" technology. These methods are also adaptable to the "future" technology - the "surface-mounted" technology, though, this adaptation is not a concern of this paper.
5. There is an order constraint on the processing of the components, which requires some to be processed first on machine 1 and others, later, on machine 2 (giving a 'flowshop' type assembly condition). The reason is that larger components (IC's) should be assembled before the smaller ones (axial and radial lead components), since the machine head (for IC insertion) may interfere with the smaller components if they are assembled first. This constraint does not exist in the placement of SMC's (surface mounted components) so that the production with SMC's is more flexible.
6. Production is a low-volume, high-mix production environment.

THE GSU METHOD

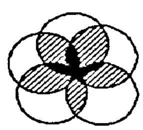
The idea behind GSU is that the PCB's are divided into groups, each of which is produced in two stages. In the first stage, the common components (i.e. components that are shared among two or more PCB's in the group) are set-up on the machines only once for the whole group, and are assembled onto their respective PCB's. We refer to this stage as the common set-up and production. The next stage, referred to as the residual set-up and production, requires the separate set-up and assembly of the remaining components on each PCB. Therefore, the production stages on each machine are as follows:

1. Set-up of common components.
2. Assembly of common components on all the PCB's in the group.
3. Set-up of residual components.
4. Assembly of residual components on each PCB separately.

A detailed example of the GSU method, and a comparison of this method to the traditional production method can be found in Freed et al 1988 (1).

A schematic presentation of the production using the GSU method is shown in Figure 1. All shaded spaces represent common components which result in set-up time savings.

Figure 1: The GSU production method



The grouping problem can be viewed as a clustering problem. Several techniques have been proposed for defining these clusters (e.g. McCormick et al 1972, Burbidge 1975, King 1980, Kusiak 1987). The technique chosen should include finding the right balance between the group size and production time, since the production planning horizon, should be relatively short - in view of the assumption that due dates are to be ignored. The savings in set-up time increase as the group size is enlarged, since each PCB type added to the group, typically contains some common components which are already set up on the machine. However, Each PCB added, also increases the production makespan and the lead time of all the PCB's in the group.

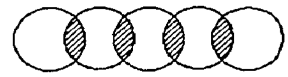
THE SDS METHOD

The second approach uses the same GT concept in a different way. The main idea is that PCB's should be sequenced such that a follower PCB will require a maximum of common components as the current PCB, *thus eliminating much of the set-up between these products. This method* was used by many authors especially in the metal processing industry (e.g. Tang 1986), where the common resources were tools and parts. Another variation of this approach, schedules products in order to reduce the waiting periods for commonly used, but limited resources like pallets (Kusiak, Vanelli & Kumar 1985). We refer to this approach as sequence-dependent scheduling. A schematic presentation of sequence-dependent scheduling in PCB assembly is shown in Figure 2, the shaded spaces representing the set-up time saved in using this method.

The production steps using SDS are as follows:
1. Determine the sequence for producing the PCB's using a TSP-based strategy (see below);
2. Set-up the components for the first PCB on both machine 1 and 2;
3. Assemble all the components on the first PCB, first on machine 1 and immediately afterwards on machine 2;
4. Set-up the components for the next PCB on both machine 1 and 2, while changing only the components which are not shared among the first and the second PCB;
5. Assemble all the components on the second PCB, first on machine 1 and immediately afterwards on machine 2;
6. Continue the set-up and assembly of all the PCB's remaining, according to the sequence in step 1.

A detailed example of the SDS method, can be found in Freed et al 1988 (2).

Figure 2: Sequence-dependent scheduling



The sequence-dependent scheduling problem can be shown to belong to the "travelling salesman" (TSP) type problem, which is NP-Complete (Cunningham & Browne 1986, Lawler, Lenstra, Rinnooy-Kan & Shmoys 1985, Lin & Kernigham 1973, Rinnooy-Kan 1976). Its complexity is even greater for this specific PCB assembly problem, since it is required to sequence PCB's (jobs) with set-ups on two machines sequentially. The optimal schedule must be determined by solving a special 2-machine TSP type problem which has never been solved to date. However, there are heuristic methods for tackling this problem, although their efficiencies have never been fully analyzed (Gelfand 1979).

Another way for tackling this problem is by reducing it to a single machine TSP problem. We do this by adding the set-up times for each PCB on the two machines - with the assumption that the sequence of production is the same on both machines (these are called "permutation" solutions). The reader is referred to Freed (1988) for a justification of this approach.

There are several techniqes for solving the TSP problem. Among them are:
1. Implicit enumeration;
2. *Integer linear programming;*
3. Dynamic programming;
4. Branch and bound;
5. Heuristic methods.

For small problems (up to 10 PCB's in the group) it is recommended to use an optimal solution seeking technique, such as branch and bound. For larger problems, the computer processing time may be prohibitively large, forcing the use of heuristic methods, such as in Christofides 1976, Golden et al 1980 and Lin & Kernigham 1973.

A COMPARISON BETWEEN THE GSU AND THE SDS PRODUCTION METHOD

The most important performance measure in industry boils down to the cash-flow of the plant/company. With respect to the electronics PCB *production being considered, there are two major factors that affect the* cash-flow: the average flow or, throughput (affecting the amount of income), and the average work-in-process (WIP) inventory (representing a production cost for achieving this flow). Labor cost is considered to be a constant cost factor in both methods, although the GSU approach suggests that some labor savings may occur. Thus, the GSU and the SDS are compared in terms of the average flow (throughput) and of the average work-in-process inventory.

COMPARING THE AVERAGE FLOW

As with many industrial environments in which lots (or, batches) are produced in sequential stages on several machines, there are two practical approaches to production. According to one, the sequential stages are totally separated. The lot begins production on the second machine only after the last product is completed on the first machine. The advantage of this method is that machine 2 does not depend on the production rate of machine 1, and can produce the lot continuously, with no idle time. We refer to this approach as "periodic production". The second approach, called "continuous production", applies to products that are each transferred to the subsequent stage immediately after they are completed in the previous one. As soon as the first product is completed on machine 1, it is transferred to machine 2 and can start being processed there. Machine 2 however, may experience idle times, especially when machine 1 processing times dominate that of machine 2 - *but the overall production lead time is shortened.*

When the production is periodic, the production makespan of each lot is always shorter for the GSU than for the SDS method, since when using GSU, the maximum set-up time is saved for each lot on each machine. Since the average flow is proportional to the machines occupation time, **the throughput must be higher for the GSU method.**

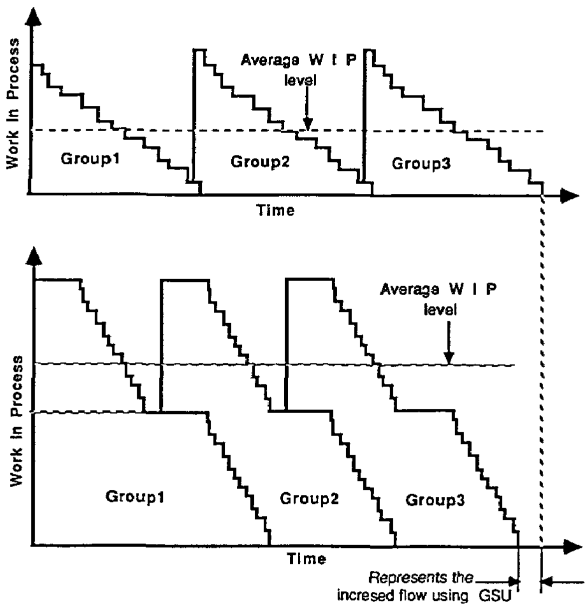
When production is continuous, the exact time (the delay) in which machine 2 should start assembling for the GSU method, so that it will have no idle time, can be readily calculated. While the machines may be used more efficiently, the production makespan remains unaffected. The machine occupation time, for both machine 1 and machine 2, is still smaller for the GSU than for the SDS production method, since more set-up time is saved on each machine. **Therefore, the throughput is again higher for the GSU method.**

COMPARING THE AVERAGE WIP LEVEL

The diagrams showing the WIP level under the SDS and the GSU methods are presented in Figure 3. It is assumed that the production of each batch on machine 1 does not begin until all the material required for production on both machines is available.

For GSU, the WIP of each group is constant until the assembly of the residuals on machine 2 begins, after which, it decreases in steps until the last PCB in the group is completed. Since a new group is introduced to machine 1 before machine 2 is completed with the previous one, the average WIP level is radically increased. With the SDS method, the WIP function is a reducing step function - each step representing the completion of a PCB on machine 2. Clearly, the average WIP level when using the GSU method is much higher than the average WIP level when using the SDS method.

Figure 3: The average WIP level under the SDS and the GSU methods



CONCLUSIONS

Two new scheduling methods for the assembly of PCB's were presented, both perform better than the traditional production method in terms of set-up time, which leads to a better performance in terms of average flow-rate (throughput). The GSU scheduling method was shown to perform better than the SDS method in terms of the average flow (throughput), whereas the SDS scheduling method was shown to perform better than the GSU method in terms of the average WIP level.
A numerical example comparing both methods can be found in Freed (1988).

The decision as to which method be implemented for a specific problem will depend on several considerations. For example, if the assembly process is a bottleneck operation, then the GSU should be selected; whereas, if the PCB assembly is not a bottleneck, then the SDS method, yielding reduced WIP levels, should be used.

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